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Kinnier, John W.

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John W. Kinnier

DRAG REDUCTION ON SPHERICAL BODIES
DUE TO CERTAIN ADDITIVES IN WATER.

Drag Red

U. S. NAVAL ORDNANCE TEST STATION
PASADENA ANNEX

P8076/[illegible]
17 July 19[illegible]

MEMORANDUM

From: John W. [illegible], Lt, USN, 592129/1100
To: J. L. Green, P8076

Subj: Drag Reduction on Spherical Bodies due to Certain Additives in Water

1. Background: While on a summer field trip from the U. S. Naval Postgraduate School, Monterey, California, I undertook the project of determining if a drag reduction phenomenon existed for spherically shaped objects falling in certain fluids. This report summarizes my findings.

2. Apparatus: (See Appendix I for a block diagram and photographs of the experimental setup.)

The experimental apparatus consisted of a three inch diameter Pyrex glass tube with a Plexiglas base and valve device, a crystal controlled local oscillator, a variable frequency oscillator, a General Radio Type 1232-A tuned amplifier and filter, and a CEC Datarite recorder.

The fluid to be tested was placed in the tube, and stainless steel balls of various sizes were dropped through the fluid. The velocities of the balls were measured in speed traps consisting of four coils spaced six inches apart. (As a ball passed one of these coils it would change its inductance, causing a change in the frequency, thus allowing detection.) A 100 cps signal, which was monitored with a frequency counter, was fed into the recorder as a time reference.

3. Determination of Drag Reduction: The equation

$$V = \left(\frac{F}{k}\right)^{1/2} \left[1 - \exp(-2kx/m)\right]^{1/2} \qquad \text{(See Appendix II)}$$

was solved by digital computer for the various balls used, and for various values of the distance of fall and the constant k. From this information curves of velocity vs. k were drawn for each ball. Since k is directly proportional to the coefficient of drag, the percent reduction for additive fluids is

$$\frac{k \text{ of water} - k \text{ of fluid}}{k \text{ of water}}$$

A more conservative expression, but easier to determine, which is based on the assumption that the ball has reached terminal velocity is

each fluid is

$$\text{Drag reduction} = 1 - \left(\frac{\text{velocity in water}}{\text{velocity in test fluid}}\right)^2$$

4. Summary of Results:

Fluid	Percent Drag Reduction for Various Sphere Diameters				
	1/2"	9/16"	3/4"	1"	Lumped
1.0% J2FP Guar II	-	-	-	5.0(3)	5.0
0.5% J2FP Guar I	-	-	31.5(15)	33.5(15)	32.5
0.5% J2FP Guar II	-	27.0(5)	28.5(13)	28.0(11)	28.0
0.25% J2FP Guar I	-	-	27.0(8)	24.5(15)	25.5
0.25% J2FP Guar II	-	-	23.0(6)	19.0(10)	20.5
0.125% J2FP Guar I	-	-	-	11.0(17)	11.0
0.75% Polyox 301	26.0(4)	-	-	-	26.0
0.50% Polyox 301	15.5(4)	15.0(7)	14.0(6)	-	15.0
0.25% Polyox 301	12.5(5)	-	-	-	12.5

NOTES:

1. The numbers in parentheses show the number of observations used to determine the results.
2. In the Guar II solutions, sugar was added to the guar to facilitate its going into solution.

5. Accuracy of Results: The results presented here were obtained by taking the simple arithmetic mean of the total number of observations. No attempt has been made to determine standard deviations, probable accuracies, etc. In general, for a given set of observations there was little deviation, and it is felt that a conservative estimate of the accuracy of velocity measurements in those trials where five or more observations were made is $\pm$ 4%.

(To check the apparatus, and to see how close the average velocity measurement would correspond to the actual velocity at a point, six drops in air were made. The average measured velocity for these drops after 3.0 ft. of fall was 13.85 ft/sec., whereas the calculated velocity using $v = (2gh)^{\frac{1}{2}}$ was 13.88 ft/sec.)

6. General Discussion: A question that is yet unresolved concerns the repeatability of results from one solution to another. From the two guar "batches" tested, it is evident that the drag reduction phenomenon existed for each. However, since the drag reduction varied between batches by up to five percent, further experimental work would be required to resolve whether this variance could be reduced by standardizing mixing procedures.

Since the amount of drag reduction was less in the batch where sugar was used to aid mixing, there is some indication that the presence of sugar affects

are complex. However, without further experimental data, this evidence is inconclusive.

The amount of data obtained with Polyox solutions was relatively small. However, it is evident that the drag reduction phenomenon does exist for this additive as well as for Guar. Particularly for the Polyox solutions, a greater effort should be made to normalize procedures, specifically the mixing rate and the elapsed time between mixing and tests.

For any further experiments on this Station, it is recommended that samples of the same fluids be tested in the HYDRAT device to see if any correlation in the results could be determined.

From observing the solutions tested, for any given concentration of additive the Guar solutions were noticeably less fluid (i.e., "thicker") than the corresponding Polyox solution. In that a greater concentration of Polyox was required to achieve the same degree of drag reduction, perhaps the mechanism of this drag reduction involves the dampening of disturbances.

In analyzing the data obtained from trials in water it is apparent that some side wall affects were present. This conclusion follows from the values of drag coefficient obtained for the various sized balls. These were

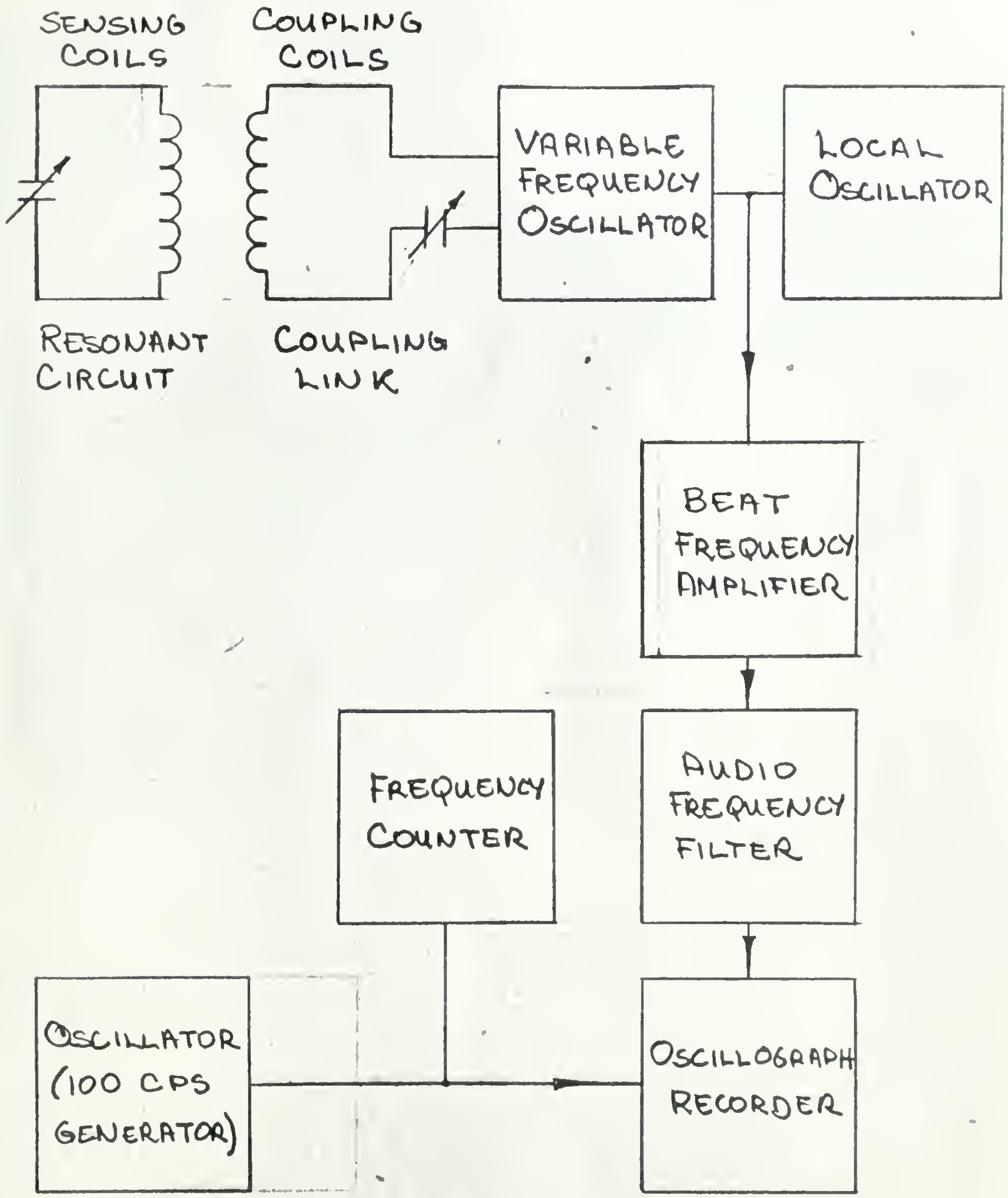
Sphere diameter:	1"	3/4"	9/16"	1/2"
Drag Coefficient:	0.64	0.57	0.52	0.49

The accepted value for the drag coefficient for all these cases is approximately 0.47. As the ratio of tube diameter to ball diameter increased, the accepted value was definitely approached. It is felt that since the density of the fluids tested was essentially that of water, the pressure gradient should be similar, and to a first order approximation at least, the side wall affects would be the same for both fluids. With this assumption, the values of drag reduction determined should be quite accurate.

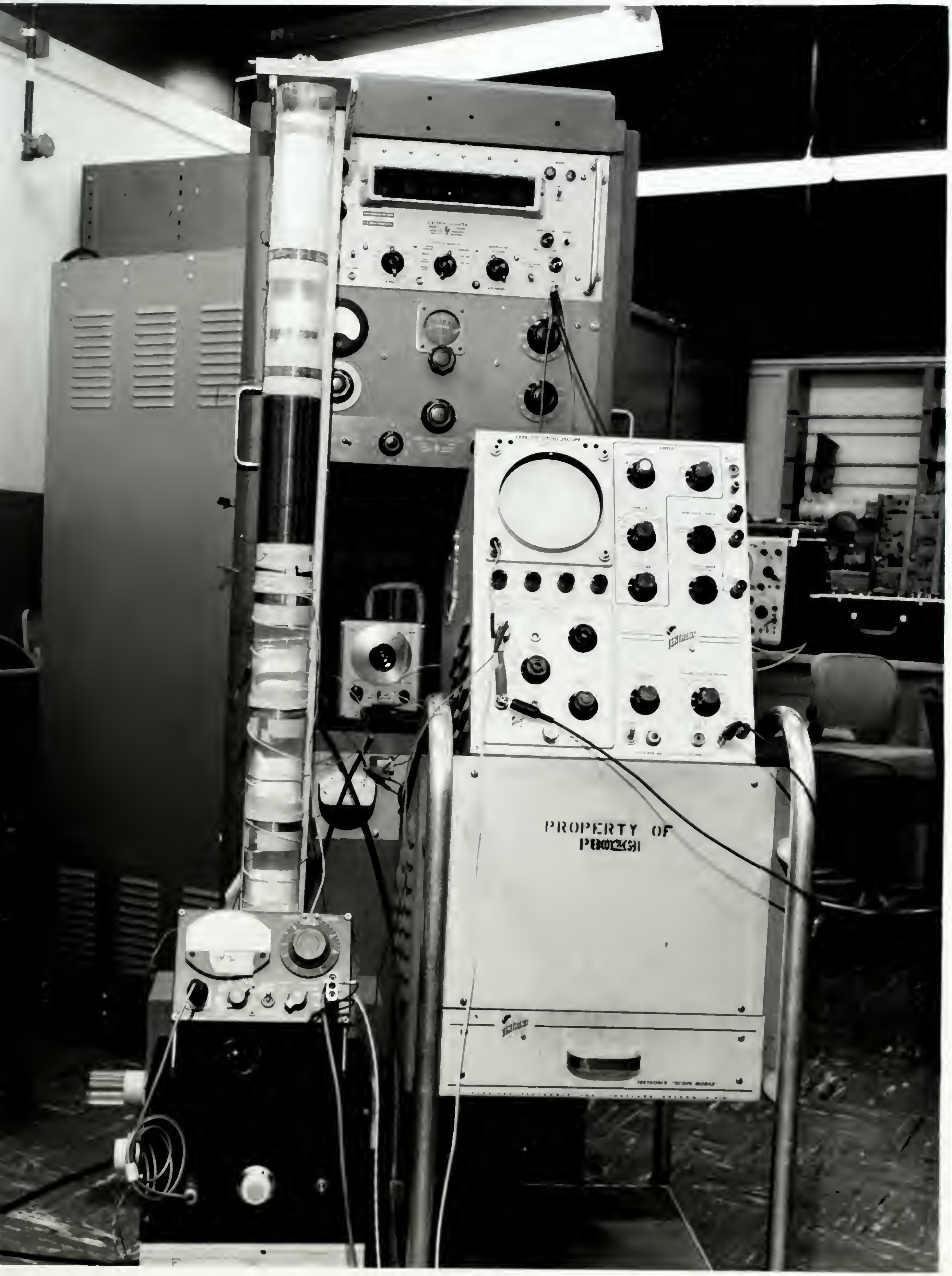
7. Conclusion: From the results of these experiments, the existence of some drag reduction phenomenon for spherically shaped objects due to certain additives has been shown. More detailed studies would have to be undertaken to ascertain the nature of the mechanism involved.

JOHN W. [illegible]
LT, USN

BLOCK DIAGRAM OF EXPERIMENTAL SET-UP



DERIVATION OF FORMULAS USED



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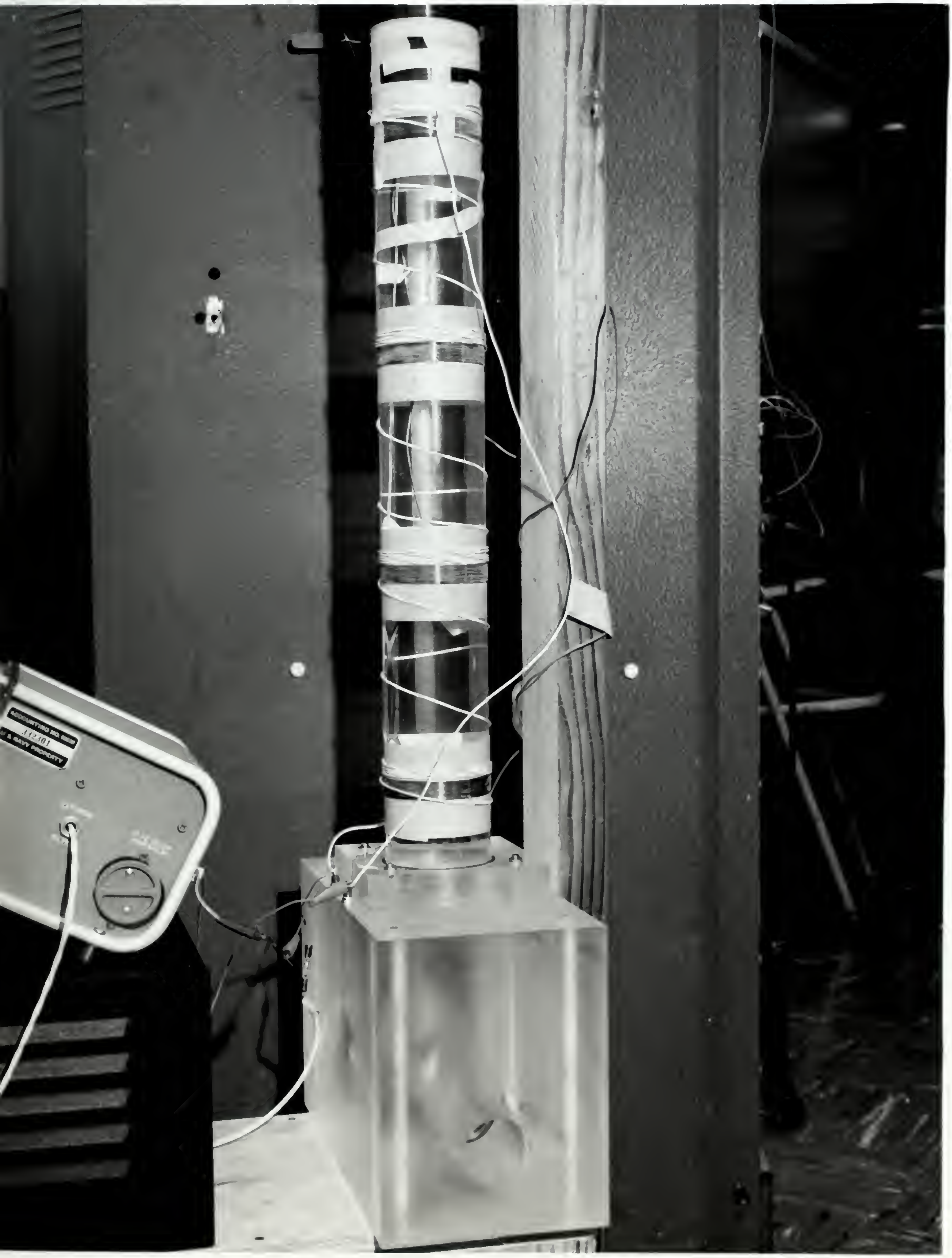
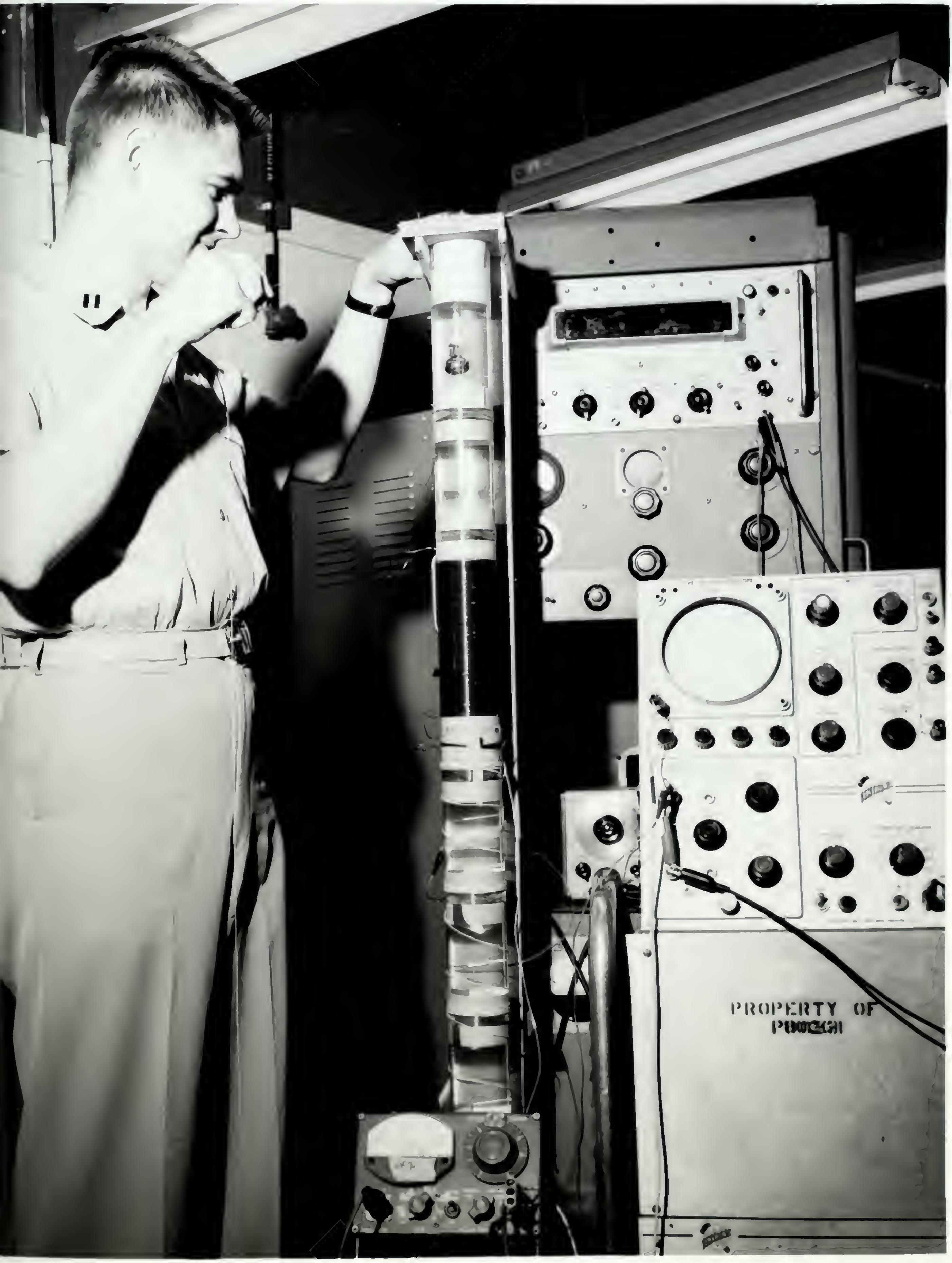


DERIVATION OF FORMULAS USED



DERIVATION OF FORMULAS USED

Symbols

W - Weight of sphere
B - Buoyant force on sphere
F - Net force on sphere $= W - B$
v - Velocity
k - Drag constant of proportionality $= \frac{1}{2} A \rho C_D$
C_D - Coefficient of drag
A - Cross-sectional area of sphere
ρ - Density of fluid
x - Distance of fall
g - Acceleration due to gravity

(All units in ft-lb-sec system)

[From $F = ma$]

$$W - B - kv^2 = ma = \frac{W}{g}\frac{dv}{dt} \qquad v = \frac{dx}{dt} \Rightarrow dt = \frac{dx}{v}$$

$$(F - kv^2)\,dx = \frac{W}{g} v\,dv$$

Thus $x = \frac{W}{g}\int \frac{v\,dv}{F - kv^2}$

or $x = \frac{-W}{2gk}\ln\left(v^2 - \frac{F}{k}\right) + C$ (constant of integration)

Setting $v = 0$ when $x = 0 \Rightarrow C = \frac{W}{2gk}\ln\left(-\frac{F}{k}\right)$

$$\therefore x = \frac{W}{2gk}\left[\ln\left(-\frac{F}{k}\right) - \ln\left(v^2 - \frac{F}{k}\right)\right]$$

$$x = \frac{W}{2gk}\left[\ln \frac{-F/k}{v^2 - F/k}\right] \Longrightarrow e^{\frac{2gk}{W}x} = \frac{-F/k}{v^2 - F/k}$$

Solving for v:

$$\longrightarrow \quad v = \left[\frac{F}{k}\left(1 - e^{-\frac{2gkx}{W}}\right)\right]^{\frac{1}{2}}$$

Note: Terminal Velocity $= \sqrt{F/k}$

A Conservative Approximation for Drag Reduction

(Assumes terminal velocity has been reached in both the fluid tested and water.)

$$\text{Drag Force} = F = \tfrac{1}{2} A \rho C_D v^2$$

$$\text{Drag Reduction} = \frac{\text{Drag in } H_2O - \text{Drag in fluid}}{\text{Drag in } H_2O}$$

$$\cong \frac{C_{D_{H_2O}} - C_{D_{Fluid}}}{C_{D_{H_2O}}}$$

$$\cong \frac{\dfrac{F}{\frac{1}{2} A \rho v_{H_2O}^2} - \dfrac{F}{\frac{1}{2} A \rho v_{fluid}^2}}{\dfrac{F}{\frac{1}{2} A \rho v_{H_2O}^2}}$$

$$\cong 1 - \left(\frac{v_{H_2O}}{v_{fluid}}\right)^2$$